WESTERN AUSTRALIA'S CONTRIBUTION TO EARTH HISTORY.

Presidential Address

to

The Royal Society of Western Australia

By

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(Delivered on the 13th of July, 1926.)

"Grant we have mastered learning's crabbed text,
Still there's the comment."

On addressing you this evening, my foremost duty and one of pleasure is to thank you for the honour conferred by electing me for the second time after an interval of ten years as President of the Royal Society for the official year which terminates to-day. The election is not only a compliment to myself; it is also an expression of your conviction that the alliance between pure and applied science, for the prosecution of economic enquiries can only be efficiently and effectively carried out in a strictly scientific manner and is an *entente* which brings lasting benefit to both.

The obligations and responsibilities which the office with which you entrusted me twelve months ago to carry are not to be lightly undertaken, in view of the growing tradition of the work of my predecessors who have occupied the Presidential Chair.

I count myself fortunate in acting as your presiding officer at a time when the affairs of the Society are in such a very satisfactory position, not only as regards finance and membership, but also in its slow and steady growth of usefulness.

There seems every reason to hope that the work of the Royal Society will continue during the incoming year equally well as it has done during the relatively short period of its existence. Nevertheless it should not be forgotten that the President and Council cannot do everything to make and keep the Society as successful as it has been and ought to continue to be without the very active support of the members themselves. It is hoped, therefore, that members will continue to evince that interest in all that makes for the well-being and progress of the Society, and that the younger members (most of whom have been trained in our local educational institutions), in whose hands the future ultimately rests, will come forward and contribute some of the results of their investigations, adding in this way their quota to the sum total of human knowledge and thus assisting in the solution of those numerous problems which have long aroused the keenest interest amongst the scientific workers of all nations.

This brief reference to what might be called the material aspect of the affairs of the Society brings the somewhat disturbing reflection that custom prescribes that the President on the termination of his year of office shall carry out the law of precedence by delivering an address on some department of science to which his attention has been more especially devoted.

There is an old proverb that "Custom must be indulged by Custom or Custom will die," and while I have no desire to depart from traditional usage, the circumstance that Western Australia hopes next month to have the honour of welcoming, for the first time in the State's history, the members of the Australasian Association for the Advancement of Science, suggests that I should depart somewhat from the usual custom and devote an academic hour to bringing under notice the main contributions which Western Australia has made to the general principles of Geological Science, the full bearings of which, owing to the relative isolation of this portion of our island continent, have not been, perhaps, sufficiently recognised.

In bending myself to this task an endeavour will be made to follow out Pindar's advice:

> "With vivid words your just conceptions grace,
> Much truth compressing in a narrow space."

It was found necessary in the year 1896 to establish a permanent branch of the Public Service charged with a more or less comprehensive and systematic survey of the geological structure of the State and all that is connected therewith. Such geological investigations involved, *inter alia*, the application of the principles of the science to the exploration and exploitation of the State's mineral deposits, which have played a very important part in its economic and industrial development, for modern industry is more dependent upon mineral products than upon the commodities of any other natural group.

In the broad area of the State pretty nearly all geological systems have their representatives in the rocks which build up the territory.

One of the most fundamental features in the geology of Western Australia is the similarity in structure of its rocks to those of the countries bordering the Indian Ocean, viz., South Africa, Madagascar, India and the Netherlands Indies. This noteworthy resemblance is paralleled in the whole of the geological formations developed in the State; a close association which being reflected in the similarity of types of Western Australian mineral deposits is of considerable economic as well as scientific interest.

The Pre-Cambrian Rocks occupy nearly 400,000 square miles out of the 975,920 which constitutes the area of the State, and contain within the boundaries practically the whole of the metallic wealth of the State, of which about £160,000,000 have been raised. These Pre-Cambrian rocks, from the standpoint of their character, the complexity of their structural relationships, their development, their origin and the changes they have undergone, contain the materials for probably one-half of the geological history of the earth. There are probably few parts of the Australian Continent which can boast of a finer development of these Pre-Cambrian rocks than Western Australia, and the variety of lithological types bids fair to make the State a classic field for petrological research. It is to these Pre-Cambrian Formations that geological attention has naturally been principally devoted on account of the economic possibilities which such rock associations offer. Investigations have shown that especially noteworthy amongst them is the presence of huge composite batholiths of granite and gneiss with some crystalline schists resulting from the transmutation and partial assimilation of the granite, together with a group of schists, mostly altered sediments, and rocks of an allied nature, as well as their more or less contemporaneous igneous associates. These igneous rocks, principally of basic composition and of somewhat different geological types, have undergone extensive and widespread metamorphism, producing rocks of the epidiorite type on the one hand and the carbonated greenstone on the other. Ultra-basic rocks, represented by serpentine, peridotite, pyroxenite, and their transmuted derivatives, are also of frequent occurrence.

The distribution of the Pre-Cambrian Rocks resembles somewhat, as may be seen by an inspection of the geological map of the State, a sea of granite, studded with great islands of greenstone and their associated sedimentaries—an arrangement stated to have resulted from crustal foundering.

A typical and noteworthy member of the Pre-Cambrian group of rocks is the brilliantly coloured compact jaspilites and cherts, grading gradually into valuable haematite deposits, many of which are several hundreds of feet wide and some thousands of feet in length. There iron-bearing jaspers occur in more or less parallel bands which at times stand out in bold relief above the ground surface and constitute important stratigraphical horizons, traceable across country for considerable distances.

The presence of such thick and extensive deposits of jaspilite and iron ore in the Pre-Cambrian formations, not only in Western Australia, but also in South Africa, India, and the North American Continent, suggests, as has recently been pointed out by a leading geologist, that conditions at the period of their formation must have been fundamentally different from those obtaining in Post-Cambrian times and that "uniformitarianism as a working principle for the geologist cannot be pushed back indefinitely into the past."

The jaspilites may have been originally highly ferruginous fine-grained grits of sedimentary origin, and the source from which the iron-bearing minerals originated was basic igneous rocks. The ferruginous bands generally follow very closely the bedding planes of the enclosing metamorphic sediments, indicating that the solutions responsible for the deposition of the iron ore were to a very large extent controlled by the stratification. In many localities bands of siliceous dolomitic limestone are associated with and gradually pass into the ribboned jaspilites; an association which suggests that some of the jaspilites and their allies originated from the alteration of limestones.

One of the outstanding features in connection with these Pre-Cambrian rocks is their distribution along what geological investigation has shown to be one of the principal lines of weakness or mobility in the crust as developed in Western Australia.

The sedimentary beds were deposited in a broad geo-synclinel and since their formation have been more or less irregularly folded and compressed, concertina-fashion, along highly inclined axial planes. The folding is meridional with a tendency to an alignment in a north-west and south-east direction. The cleavage or schistosity commonly follows a like direction. In this geo-synclinal basin, which extends from the Recherche Archipelago on the South Coast to that portion of the North West coastline into which the De Grey, Yule, Fortescue, and Ashburton Rivers discharge their drainage, were deposited vast amounts of sediments carried by swift-running rivers issuing from the series of broad mountain ranges, which have since been worn down to base level by a cycle of erosion.

These rocks form part of that bow-shaped great circle which in Pre-Cambrian times extended from Western Australia across the north-eastern portion of the Indian Ocean, through Peninsular India, the Hindoo Koosh Mountains, down what is now the valley of the Oxus, and thence along that narrow belt between Eastern Europe and Western Asia—the Ural Mountains—and disappearing beneath the waters of the Arctic Ocean in the vicinity of Nova Zembla and the Kara Sea.

The beds in Peninsula India have the same general trend, lithological character, tectonic structure and community of origin as their Western Australian representatives. They disappear beneath that enormous development of horizontal basaltic lava flows, the Deccan Traps of Central India, reappearing in Udaipur and emerging from beneath the recent beds of the Indo-Gangetic Plain in the frontier ranges which separate the Indian Empire from Afghanistan and Turkestan. In the Hindoo Koosh Mountains fragments of these Pre-Cambrian rocks still exist, though much broken and shattered by those later earth movements which raised the Alpine-Himalayan and Dutch East Indies mountains during the Tertiary period, and which crossed the former almost at right angles, thus dividing the hemisphere into two halves.

Crossing the Himalayas and the frontier ranges, the beds reappear in the Ural Mountains. Here is a long belt of crystalline and metamorphic sedimentary rocks associated as in India and Western Australia with those characteristic red and other coloured ribbon jaspers, in addition to being invaded by gold-bearing acid dykes and quartz reefs.

Over the vast area of this Great Circle, there is a surprising uniformity in the character of the mineral deposits, as regards alike their geological relations and their structural and mineralogical features.

These long lines of weakness and mobility are also the zones of greatest vulcanism and concomitant earthquake activity. Volcanic eruptions, together with their cognate activities are the consequences of the major movements affecting the earth's crust, and produce, *inter alia*, a general heating and local increments of the temperature gradient. It is for this reason that the central portion of Western Australia in the regions of the geo-syncline to which previous reference has been made, has revelled in a long period of igneous activity, with its great crushing and folding movements, in the Pre-Cambrian period of its geological history.

The volcanic and allied igneous rocks, several of which are lavas, some sills, and others differentiation products, are in many areas much more abundant than the sedimentary members, though representatives of each occur in nearly every belt. The basic rocks —"greenstones"—probably originally dolerites—are of variable lithological types and in common with the other members of the Pre-Cambrian formations have undergone extensive and widespread metamorphism, producing on the one hand rocks of the epidiorite type, and on the other the carbonated greenstone type. Ultra-basic rocks are represented by serpentine, talc-schist, etc. An extensive development of the rare type of hypersthene-bearing rocks, with a marked persistent mineral banding similar in character and mode of occurrence to those of the Charnockite Series of West Africa, India, Norway and parts of the North American Continent, has been recognised in the Fraser's Range, to the north of Israelite Bay.

The Pre-Cambrian rocks have been invaded by huge composite batholiths and veins of granite which extend over some hundreds of square miles. They frequently have a schistosity developed along their lines of contact with the rocks into which they intrude. The acid batholiths and their satellitic intrusions are largely biotite-granites, usually made up of microcline, oligoclase and quartz, with a marked mineral banding or gneissic structure well developed. These extensive granite masses are traversed by many great dyke-like masses of white quartz which represent the end ultra-acid product of the differentiation of the granitic magmas. The intrusion of the granite and its allies is perhaps the most important event in the geological history of the State at this early period, inasmuch as with them are associated, areally and genetically, the most important gold and other metal-bearing deposits which place Western Australia in the front rank of mining countries in the British Empire.

Viewed in the light of its structural geology, coupled with the nature, variety, and wide distribution of its mineral deposits, Western Australia appears to be one of the most remarkable mineral regions on the Australian continent. According to researches which have been carried out, it appears that 235 mineral species have been already met with in the State. Of the rarer minerals, which occur as accessory constituents in the apophyses of the granites, and have a wide distribution in the State, thirty-six are confined to Western Australia and have so far not been recorded from other parts of the Commonwealth. Whilst Dr. Simpson, by whose researches our knowledge of the mineralogy of the State has been so much advanced, notes that the three minerals hitherto unknown to science, discovered by him, viz: Pilbarite (one of the uranium minerals), Goongarite (an argentiferous sulphide of lead and bismuth), and Tantalofergusonite (a rare mineral of the yttrium group) have not yet been met with anywhere else. The tantalate and niobate of antimony, Stibiotantalite, the first discovery of tantalum ore in Australia, was made in Greenbushes in 1893 and has so far been found only in California.

To these may be added the group of telluride minerals which occur in but few localities throughout the world and which have been so extensively mined at Kalgoorlie and Boulder, the chief gold-producing centre of the State.

The tellurium-carrying minerals constitute one of the most distinguishing characteristics of the ores of Boulder and Kalgoorlie, being the main source of over 16 million ounces of gold from this mining centre.

With such an *embarras des richesses* in the broad domain of mineralogy it is not at all surprising that Western Australia's contributions to what may be termed mineralogenesis have been so extensive and of such a high order.

The igneous rocks occurring in and associated with Pre-Cambrian formations have also thrown a great deal of light upon many of the more important problems of petrogenesis.

An outstanding feature in connection with the investigations is the important part which the upwelling of the molten granite and its complementary dykes, with the concomitant sagging of the overlying rocks into intervening troughs, has been found to play with regard to the gold-bearing and other mineral deposits.

A result of this granitic invasion has been the formation of fracture planes and other lines of weakness, having a general north-westerly alignment, along which the mineral-bearing solutions in circulation have found an easy passage, with the introduction of the metalliferous minerals; this being the latest expression of the subterranean forces in operation.

It is therefore the rocks along and adjacent to the margins of the granites which have proved to be the hosts for ore and which constitute the chief hope for an expanding mineral industry.

The existing land surface bears no relation whatsoever to that which existed when the ore bodies were formed. The limits of ore deposition, i.e., cooling and consolidation, are not confined to a few hundred feet from the surface, but are to be measured in miles rather than in fathoms. The inferior limits of mining, when viewed from the broad standpoint, are determined rather by the cost of production than by the exhaustion of ore.

Ore formation processes are at present in active operation at enormous depths beneath our feet, for such appear to be due to underlying causes that have been more or less continuously in operation from the earliest of geological times.

Modern writers on the natural history of ore deposits call attention to the connection between quartz veins and acid pegmatite dykes (the off-shoots from the granite) and their community of origin. In this connection it may be pointed out that my colleague, Mr. T. Blatchford, in his account of the geology of the Coolgardie Goldfield, published as far back as the year 1899, described the transition from the normal granite of the field, through auriferous acid dykes to pure quartz veins, distributed marginally with reference to the mass of intrusive granite, which in this part of the Central Division covers such an extensive area.

The mining centre of Westonia, on the Yilgarn field, also furnishes further important evidence of the intimate relationship which exists between the auriferous quartz veins and the normal granite of the district. The quartz, which contains rows of fluid inclusions, is intimately associated with felspar, both of which appear to have solidified at about the same time, and are merely varieties of a quartz-felspar pegmatite, an acid differentiate of the granite magma.

In this connection it is interesting to note that the origin of gold-bearing quartz veins as a result of differentiation from a granitic magma is not by any means new. As far back as the year 1861 that well-known naturalist and mining engineer, Thos. Belt, first pointed out in a paper entitled "Mineral Veins, an enquiry into their origin, founded on a study of the Auriferous Quartz Veins of Australia" that "quartz veins are as naturally produced by granitic eruptions as the acorn to the oak." In the year 1873 this author again approached this subject and in a work entitled "The Naturalist in Nicaragua," where he managed a gold mine, he wrote:

> "Mineral veins in granitic districts occur in regular sequences . . . There is also, sometimes, a complete gradation from veins of perfectly crystallised granite, through others abounding in quartz at the expense of the other constituents up to veins filled with pure quartz."

It may therefore be of interest to those engaged in the historical study of the researches into ore deposits to note that the conception sixty-five years ago, of the idea of the source of certain types of gold-bearing quartz veins as the end product of the differentiation of a granitic magma came about as a result of investigations into the goldfields of Australia, a fact which eminent geological writers on this subject have overlooked.

With regard to the Natural History of the Ore and Gem-bearing Pegmatites, the late Mr. H. P. Woodward made the important observation that the acid dykes of the Greenbushes Tinfield gave evidence of metasomatic action after solidification.

A complete series of rocks "illustrative of the gradual transition from a pegmatite composed mostly of albite, through greisen, into a pure quartz specimen, which when examined microscopically still exhibits the granitic structure, whilst tourmaline and cassiterite are the only associated minerals, which have so far been found to exist throughout the entire series" was obtained. Since the date of these observations in 1908, geologists have come to much the same conclusion from investigations carried out on the pegmatites of other mining districts in Africa, America and elsewhere.

The general geological structure of the State's principal gold producing mining centre, the East Coolgardie Goldfield, which has yielded about one half of the total gold output of the State, has now been definitely established. The gold deposits of the productive area, appropriately designated the "Golden Mile," are virtually confined to a group of genetically related rocks, originating by the transmutation of a quartz-dolerite (diabase) which is traversed by a number of acid dykes of variable width and of considerable length. The gold deposits are chiefly masses of crushed and fractured country rock of great horizontal extent and lenticular in shape, which have been metasomatically replaced and impregnated with quartz, pyrites, and other sulphides, so as to form exploitable ore bodies without any well defined walls. The gold occurs in the Boulder lodes both in the native state and, as has been previously pointed out, in combination with tellurium.

The most plentiful of all the tellurides of Boulder is the mineral Calaverite, the telluride of gold, occurring in large lenticular masses. One of the finest specimens, from the Golden Horseshoe Mine, consisted of a solid mass of Calaverite 6 inches long, 5 inches wide, and a quarter of an inch thick. The telluride of mercury, Coloradoite, is, with the exception of Calaverite, the most widely distributed of all the tellurides. Magnificent specimens have been met with during mining operations and masses several pounds in weight have been recovered. One of the finest specimens, from the celebrated "Oroya Shoot," which alone has produced nearly £8,000,000 worth of gold, consisted of a lens of Coloradoite about 5 inches long, 2 inches wide, and an inch thick, embedded in a green sericite schist, is now in the Geological Survey Collection.

It is a remarkable circumstance that though Boulder is as it were the home of the telluride minerals, few if any crystals with plane surfaces have yet been met with. It has pointed out by one of the leading living mineralogists of Great Britain that "with the occurrence of such large crystalline masses of telluride there can be but little doubt that one day crystals will be found, and these will in all probability surpass those hitherto met with from other parts of the world."

The ultimate derivation of the gold in the Boulder group of lodes would appear to have resulted from the action of a later series of igneous intrusions than that in which the ore bodies are contained. It may be that the introduction of the gold bears an intimate relationship to the after-effects of the intrusive granite which makes such a prominent feature in the country adjacent to Kalgoorlie on the north, but which has not reached the surface in the vicinity of Boulder, though it is probably represented by the acid dykes which traverse the field.

One remarkable and outstanding feature in the State is its iron ore resources, some of which are probably equal in size to other known deposits in the world. The most important class of ores in Western Australia are the large deposits of haematite associated with fine-grained sedimentary quartzites; these pass by all gradations through varieties of jaspilite to pure iron ore.

The ores themselves, in the light of such knowledge as is at present available, appear to owe their origin by hydrothermal processes, which collected and re-deposited the iron from adjacent basic igneous rocks. The highly ferruginous bands are generally found to follow the bedding and other structural planes of their hosts very closely, indicating that the solutions responsible for the deposition of the iron ore were to a very large extent controlled by the stratification. In some cases, however, there is distinct evidence of a complete replacement of the siliceous rocks by haematite, indicating that it has in part, at any rate, replaced the beds which have shared in the severe folding, faulting and compression to which they have been almost everywhere subjected.

The ultimate source of these enormous quantities of iron ore is as yet one of the many unsolved geological problems upon which much intensive research, both in the field and in the laboratory, is required.

An interesting occurrence of a chrome iron ore of some scientific importance has recently been discovered by Mr. Blatchford from the neighbourhood of Murrunda, a range of hills forming the headwaters of Skeleton Creek in the North-West Division. The deposit lies in a belt of serpentine about 80 chains in width, and the ore occurs in a series of massive lens-shaped or pod-like bodies from three to six feet wide, which average about 82 per cent of chromite. The serpentine appears to have been derived from either a pyroxenite or a peridotite in which the chromite is present as a primary constituent. Whether these lenses of chromite were segregations from the direct cooling of an igneous rock, or owe their presence to replacement since consolidation, yet remains to be investigated.

The occurrence of the mineral alunite (a sulphide of aluminium and potassium) at Kanowna, in the East Coolgardie Goldfield, in an aureola of alteration surrounding a mass of acid porphyry at Red Hill intruding the metamorphic sediments, is of considerable scientific importance. The alunite occurs in veins varying from a mere thread up to two feet in thickness, which may represent off-shoots from the porphyry. The mineral may owe its origin to percolating water charged with sulphuric acid, resulting from the decomposition of pyrites, or by sulphurous exhalations from an extinct volcano acting on felspathic rocks. The Red Hill porphyry and the satellitic dykes form the denuded relics of an ancient eruptive vent.

An unusual and unique type of an alunite deposit, and one not recorded from any other country, has been met with at Lake Brown, near Burracoppin. The deposit occurs in one of the clay pans which form part of an ancient watercourse draining into the Avon River. The material of which the deposit is made up is in the form of a fine powder consisting of quartz, kaolin, mica, felspar, salt and gypsum with some organic matter, and has been found to contain 30 per cent or more of alunite.

The mineral pyrites, reported by Mr. Bowley as occurring in some of the adjacent rocks, is probably the original source of the sulphuric acid required for the formation of the alunite.

It will have been apparent from the earlier portion of the address that Western Australia presents many geological problems of absorbing interest upon which research is required, but there is one connected with that great climatic revolution in the history of its Middle Ages (about 50 or 100 million years ago), resulting in a widespread refrigeration of a very large portion of the State, which provides almost as strong attractions as the pages of romance, viz., the Permo-Carboniferous Glaciation.

No period perhaps in the geological history of the State is of such importance and appeals so powerfully to our senses or comes into such close and intimate contact with our material wants and enjoyment as that of the Permo-Carboniferous, to which the Collie and Irwin River coalfields belong.

The Western Australian Permo-Carboniferous glaciation marks perhaps one of the most important episodes in the geological history of the State. The Permo-Carboniferous period combines many varied aspects; and being the greatest ice-age through which the world has passed, it renders the geological details of absorbing interest—upon which much still remains, and will always remain, to be done.

Investigation and study of this refrigeration is one of more than mere local significance, for it forms an important and integral part of the glaciation of the Southern Hemisphere during this geological period.

There is also its economic importance, for despite the fact that there is an extensive area of rocks belonging to the Permo-Carboniferous or Coal-forming Period in the North-West, Central, and Kimberley Divisions, they have almost everywhere proved to be destitute of coal. A large portion of these divisions having been covered by a great ice-sheet during this particular coal-forming period furnishes a possible explanation as to why there are no coal deposits, for there was neither sufficient vegetable growth to produce them nor were the geological conditions favourable for their accumulation and preservation. While the Western Australian Permo-Carboniferous glacial deposits owe their chief importance to purely scientific considerations, they do, however, mark very important stratigraphical horizons which not only tend to make possible geological correlation over the Australian Continent, but permit comparison between the Western Australian formations and those in other portions of the world.

Despite the interest which the discoveries of the evidences of this important great ice-age in the State arouse, it is only possible to deal this evening with the salient issues in an all too brief a manner.

Wherever the beds of the Permo-Carboniferous system of Western Australia have been examined they have been found to be divisible into (a) a lower, or mainly limestone series, and (b) an upper, or sandstone series, with, in the Irwin and Collie districts, some coal seams. The beds associated with the coal-bearing members of the system contain abundant representatives of a flora characterised by several species of the fern-like plant, *Glossopteris*, which has not only a wide distribution but is so abundant that some of the rocks are largely made up of its tongue-shaped and reticulately veined fronds.

The limestone series contains a rich assemblage of marine fossils, characterised by the frequent occurrence of a large number of species of the brachiopod, *Productus*.

There is a bed near the base of the formation crowded with boulders bearing the usual marks of glacier transported materials, such as rocks with smoothly planed and facetted surfaces and striations. Such deposits have been recognised at a great many localities in Western Australia, extending over 12 degrees of latitude, and to within 16 degrees of the equator. It having been found convenient to have a name for this important horizon, the term "Lyons Conglomerate" has been adopted, from the official designation of the Land District in which it was first discovered and where it is so well developed.

Where this conglomerate cannot be seen its presence is always indicated by the heterogeneous collection of boulders with which the flats are covered and which are derived from the weathering, *in situ*, of the boulder bed.

In a channel cut by the Wyndham River in the North-West Division, through the Arthur Range, there is an important exposure of the boulder bed, which is not more than three feet thick in this locality. It is crowded with boulders and pebbles of the crystalline rocks to the east, embedded in a calcareous fossiliferous matrix containing fragments of *Polyzoa*, the brachiopods *Spirifera* and *Productus*, in addition to the mollusc *Aviculopecten tenuicollis*.

The bed in which these boulders and pebbles occur is beyond all doubt of marine origin, as is proved by its fossil contents; it therefore can hardly be a glacial moraine and it is more than likely that the materials of which the bed is made up were transported by floating icebergs that drifted seaward after they had been broken off from some extensive ice sheet which came down to sea-level in a somewhat similar manner to the Great Barrier ice of the Antarctic Regions.

In the circumpolar regions of both hemispheres boulder bearing clays, muds and sands, which owe their origin to the distribution of continental debris carried seaward by floating ice, are at the present time being laid down over a very large area of the ocean floor, and these if consolidated would produce beds in every way identical to the Lyons Glacial Conglomerate.

There is in the Kimberley Division a large development of Permo-Carboniferous rocks which have yielded a remarkably rich assemblage of fossils.

It was pointed out in the year 1907 that although no glacial boulder beds had at that time been recognised in Kimberley within 16 degrees of the equator, their discovery in that region would cause little surprise. It is interesting in this connection to note that a conglomerate containing facetted and ice-scratched boulders has recently been discovered by Messrs. Blatchford and Talbot in the valley of the Fitzroy and its tributaries. This boulder bed is without doubt the equivalent of the Lyons Conglomerate. The Kimberley Permo-Carboniferous beds are believed to underlie nearly the whole of the so-called Great Sandy Desert, which nearly brought to grief Colonel Warburton's expedition in the year 1873. The southern margin of the formation lies in the valley of the Oakover River, which enters the sea between Condon and Port Hedland.

An important discovery of a somewhat sandy matrix crowded with glacially striated pebbles was made in 1924 by Mr. F. G. Clapp, an American geologist with considerable experience in glacial deposits, on the southern flank of the Great Sandy Desert, near Braeside Station on the Oakover River, which there are sound reasons for believing to be of Permo-Carboniferous Age.

Another very important discovery of these glacial deposits or more than local significance was made in 1916 by my colleagues, Messrs. Talbot and Clarke, in the Wilkinson Range near the South Australian Border in South Latitude 26° 30'. For over a distance of 200 miles between the Range and Axe Hill there were found numbers of pebbles and boulders of many different rock types, weighing several hundredweight, derived from the disintegration of a conglomerate about 15 feet thick. Attempts to correlate the Wilkinson Range beds with others containing evidence of ice action have not so far met with much success. There is, however, some little evidence indicating a possibility of these being on the same geological horizon as the glacial conglomerate of the Finke River in South Australia, to which the Gascoyne and other beds belong.

The ice which produced the Lyons Conglomerate did not owe its origin to what may be called the alpine type of glacier, but rather to a broad continuous ice-sheet with a thickness of hundreds or possibly thousands of feet which spread across 800 miles of country north and south and for an almost equal distance east and west.

The climatic conditions under which the Western Australian glacial beds were formed offer a peculiarly fascinating subject for enquiry and the first question which naturally suggests itself is what brought about that phenomenal refrigeration, the evidences of which are only manifest in Western Australia, India, South Africa and South America, but also in Eastern Australia.

The occurrence of glacial conglomerates near the base of the Glossopteris-bearing beds in these widely separated localities in the four continents, points conclusively to their resulting from a common cause.

It would take far too large a draft upon your time to attempt even a cursory examination of the various causes which have been sought to account for this Permo-Carboniferous glaciation, as these are somewhat outside the scope of this address. The exact explanation of this glaciation is not, however, quite clear and it would seem to remain as yet an unsolved problem, though it may be that as the question of past geological glaciations becomes more thoroughly investigated such may be found to result from a combination of factors both local and general.

It has been pointed out that "the discoveries of Australian glacial geology . . . are not only the most important that have hitherto been recorded (all the States of the Commonwealth have been more or less under the influence of glacial conditions), . . . but may fairly rank amongst the most important contributions ever made to our knowledge of the glacial geology of the world."

Prior to the time when the Permo-Carboniferous ice-floes drifted about loaded with boulders and silt, and which on melting scattered their debris along the shore line and over the sea-bottom, Western Australia formed an integral portion of that southern continent linking together South America, Africa, Madagascar, India and Antarctica. This continent, which has been named Gondwanaland, formed a barrier between a southern ocean and a great central Eurasian sea, extending across northern India where the Himalayas now stand, into Europe, and of which the Mediterranean is but a very small relic. There are also sound scientific reasons for thinking that Australia at this geological period had direct connection with Antarctica and thence to South America, and that Western Australia formed a somewhat remote corner of Gondwanaland. The great revolution in physical geography which resulted in the dismemberment of the old continent of Gondwanaland, produced, *inter alia*, the present continent of Australia by, as based upon what is nowadays known as the Wegner Drift Hypothesis, a disruption and drifting of parts under tidal influences, which gradually became widely separated by vast stretches of ocean having a depth in places of several miles. On the assumption that this continental wandering is a correct interpretation of the facts, it follows that ancient Gondwanaland must have had a very much smaller area than has been usually pictured.

If, as has been inferred, South Africa is the Mother Continent from which "South America on the one hand, and Madagascar, India and Australia, with their surrounding areas, on the other, have split off and drifted away," it is to the westward, across the wide expanse of the Indian Ocean where much of the evidence calculated to explain many of the problems of Western Australia's past and present geological history is to be looked for. According to the continental displacement hypothesis, the Indian Ocean has been formed gradually by Australia becoming detached from Africa and wandering slowly to the eastward. This implies a horizontal instability of continental land-masses which has an important bearing on the question of the permanency of ocean basins, about which much has been written in recent years.

Whatever may have been the causes which led up to the dismemberment of Gondawanaland, it gave to Western Australia many of its important features, and in a measure outlined the present configuration of the State. An inspection of a geological map of Australia shows that the continent is split right across by a broad belt of marine strata which separates it from an eastern and a western island. The larger of these islands comprises Western Australia, except the north, and the greater part of South Australia. Being the home of the characteristic Australian flora and fauna, it may be designated Australian Australia. The smaller is a long narrow island which extends from Cape York to Tasmania. As this island was connected with and received from Asia many plants and animals, it might be conveniently named Asiatic Australia. The Cretaceous sea which separated Australian from Asiatic Australia was shallow as is shown by the strata which were deposited all over its area, and in this respect resembled the Arafura Sea of to-day, though the climatic conditions were very different. The climate was comparatively cool and reef-building corals could not grow. It is significant that corals are rare in the Australian Cretaceous strata. In Western Australia the group is represented by a new species of *Coelosmilia*, met with in the strata at Gingin, which is the third representative of the corals found anywhere in the Australian Cretaceous strata.

Australian Australia enjoyed bountiful rains, thus possessing insular as distinct from continental climates. The extent of the Cretaceous rocks points to these two having been well watered, for it is the water-borne waste of the land which formed the rocks in the bed of the sea. This ancient Cretaceous sea extended into the Great Australian Bight. The strata met with in the bore put down at 337 miles 61 chains from Kalgoorlie, penetrated at a depth of 667 feet a series of shaley beds which yielded two fossils, the molluscs *Aucella hughendensis* and *MacCoyella corbiensis*, forms which are characteristic of and abundant in the Cretaceous rocks of South Australia and the eastern portion of the continent. Remnants of this ancient Cretaceous sea are also to be found in the maritime districts of the western portion of the State, where they cover a very large surface area, and are in very many places concealed beneath a cover of later deposits; whilst their presence has been proved by boring operations.

There are two distinct faunal regions of this age in Western Australia, viz.: those occurring in the strata beneath the Nullarbor Plains, at the head of the Great Australian Bight, and those of Gingin and its surroundings, to the north of the metropolis. The Cretaceous rocks of Gingin consist of a thin bed of chalk—the only one in Australia—below which are "greensands" and clay shale. The chalk of Gingin is an ancient moderately deep sea foraminiferal deposit somewhat analogous to the Globigerina ooze now found on the floor of the Atlantic. The total amount of extraneous mineral matter in the rock being small, and the quantity of recognisable minerals still smaller, it may reasonably be concluded that the Gingin chalk was formed in clear water of some depth in a region where there were no volcanoes, and at some distance from land. The fauna of the Cretaceous system as developed in Western Australia is remarkably rich, especially in formainifera and ostracoda. The Cretaceous rocks of Western Australia are of far more than mere local importance, since the elements in their fauna connect them with those of South Africa, Portugese East Africa, Eastern Madagascar, Western Peninsular India, and Assam.

The Cretaceous sea was gradually becoming shallower owing to a steady elevation, as is evidenced by the preponderance of sandy rocks in the upper members of the Cretaceous formation. Elevation continued until the whole of the Trans-Australian Cretaceous sea became dry land, and for the first time Australian and Asiatic Australia became one great continent. It was the earliest federation of the States of the Commonwealth. The geological federation was complete and final and with it there came inevitable deterioration, for the drying-up of the Cretaceous sea caused the dessication of the central portions of the continent, and the climate became hotter and drier.

Following the period of elevation and erosion at the close of the Cretaceous, the Tertiary era was inaugurated, somewhere about 10 to 15 million years ago, by a subsidence below sea-level of a great part of the country at the head of the Great Australian Bight and portions of what are now the line to the westward. With the advent of the Tertiary era there were ushered in important changes in the topography and geography of the globe. First in order of importance was the formation of that great zone of elevated plications, the result of successive movements of elevation, which extended from the Atlas Mountains in Morocco to the Himalayas, and thence prolonged through the Malay Peninsula, the Dutch East Indies and New Guinea. This immense upheaval was accompanied by the gradual draining of the interior of Australia and by the sinking of other parts of the pre-existing land.

The general instability of the Western Australian area about this time is evidenced by the fracturing of some of the coastal areas by extensive faults, having apparently considerable downthrows westward towards the Indian Ocean. The Darling Range fault scarp, which extends from the south coast northward over 6 degrees of latitude, in all probability forms the eastern boundary of a series of sunken strips of the crust, of which the western wall is to be found in that narrow ridge of ancient crystalline rocks from Flinders to Geographe Bay. The fundamental rocks of the islands of Rottnest and Houtman's Abrolhos possibly mark its northward extension. The sharp trend northwards of the Murchison River close to its mouth and the remarkable coastal indents near Shark's Bay are suggestive of its prolongation in that direction.

Shortly after the deposition of the Tertiary strata there came a period of temporary elevation, erosion and igneous activity. Extensive basaltic eruptions, probably through long conduits rather than great volcanoes, together with eruptions belonging to the intrusive phase took place in the western portion of the South-West Division and probably reached its climax during the early stages of the late Tertiary period and became subdued if not surpressed at the end of this time prior to the Pleistocene epoch, together with the formation of the Coastal Cave Limestone.

The grim-black terraces of basaltic lava flows are to be seen on the sea coast at Bunbury and elsewhere on the south coast. They may also be seen in the Capel River, at several places in the valley of the Blackwood, and near Silver Mount between the Warren and the Donnelly Rivers; they were also cut in two of the bores put down in the search for petroleum in the Warren River. The basaltic lavas, covering an area of about 3000 square miles, remain as a fragment of the enormous flows which probably spread over the extreme south-western portion of Western Australia, and probably over a much larger portion now buried under the Indian Ocean and the sea along the south coast.

In the inland area of the Central Division there are many scattered veins and dykes of remarkably fresh dolerite, which, as at Norseman, can be followed across country for several miles. At times they may be seen intersecting the gold-bearing deposits. These may possibly belong to the same period of Tertiary igneous activity as the basaltic lavas.

The only direct evidence of the geological age of the olivine-dolerites at present known is met with in the neighbourhood of Albany, where a basic dyke is seen to intersect a member of the Plantaganet Beds, the organic remains in which prove them to be Miocene Tertiary. The dolerite dykes and basic lavas seem to belong to one series and reached their present position at about the same geological period. The dykes therefore are of late Tertiary age and belong to the same period as the volcanic rocks in South Australia and Victoria.

In the North-West Division a remarkable and very important feature is the abundance of dolerite intrusions in the form of sheets or steeply inclined dykes. These rocks have a remarkably uniform composition and exhibit little or no trace of recrystallisation or other signs of metamorphism, and are practically in the same condition in which they originally congealed. Some of them extend across country in more or less straight lines for many miles and give rise to fairly conspicuous features standing out boldly in the backs of the ridges, of which an excellent example, the Black Range, is to be seen in Pilbarra. At times these dykes and sheets invade the sedimentary rocks along the planes of bedding and occasionally arch up the overlying strata; whilst at others they form tapering sheets running out into the neighbouring sediments in form not unlike a cedar tree.

From the number and very large area over which these dolerite intrusions extend it appears that there must have been a huge reservoir of molten matter lying beneath the surface to the north of S. Lat. 26° which merely awaited the suitable opportunity of rising to the surface.

In the far north, in the Kimberley Division, basic lavas and volcanic ashes occur in great force. These lavas appear to have flooded the valleys of the Ord and Bow Rivers and levelled up the depressions, with the exception of certain knife-edged ridges of the older rocks which still protrude above the general level. On the Behn River, just above what is known as the Gorge, is a dome or "puy" of basalt which formed one of the foci from which these lavas issued. None of the volcanoes are still active, though the hot spring at Mount Wynne points to the fact that the igneous activity has not yet been entirely surpressed.

At the close of this geological period a great part of the southern coastal plain and the adjacent borders of the interior plateau were raised above the sea-level, but the full extent of this uplift is not as yet definitely known, but it is certain that the sea retreated considerably beyond its present shore line.

Part of the Western Australian coast line is occupied by a rock series designated the Coastal Limestone, the unequal weathering of which has resulted in the formation of an extensive system of caves and grottoes which yet await exploration. The coastal limestone contains abundant fossil mollusca, identifiable with those at present living in Australian waters, and furnishes unmistakable evidence of a distinctly warmer climate than at present obtains in these areas.

From the Mammoth Cave, on the Margaret River in the extreme south-west portion of the State, over 10,000 bones or fragments in an excellent state of preservation have been unearthed from beneath a layer of stalagmitic material which covered the floor.

The mammalian fauna of the Pleistocene caves of the Margaret River has been in part described in a series of publications issued under the aegis of the Trustees of the Western Australian Museum. A vast amount of material has still to be worked out and it is hoped that such will be put in hand at an early date as the investigations bid fair to open up important and fascinating phases in the ancient mammalian history of the State.

Careful and systematic exploration of these limestone caves and the numerous rock shelters and grottoes of the Central and other interior regions may possibly prove them to contain priceless fossil evidence capable of throwing light upon the origin of the Australian aborogines and incidentally that of the human race, and the location of the original home of mankind.

Many of the sedimentary and other residual deposits occurring in widely separated districts of the State weathered out into shallow caves which provided rock shelters frequented by the native races, whose former presence is indicated by stone and other implements, and fragments of bones of birds and animals, as well as realistic paintings of men and native animals done in colour on the surface of the rocks, many of them giving evidence of artistic skill of a relatively high order.

Palaeontological research on material from Western Australia virtually began with investigations made into the collections made during that early period devoted to official exploration and survey long prior to the commencement of more or less systematic geological work. The fossil collections made by Mr. F. T. Gregory between the years 1830 and 1861 gave the first evidence of the presence of Mesozoic rocks in the State in addition to furnishing an account of the scanty Carboniferous faunas occurring in rocks of the valley of the Lyons River, east of the Kennedy Range in the watershed of the Gascoyne, and on the Irwin River. This was followed in 1862 by the work of Mr. Charles Moore, F.G.S., on the collection of Mesozoic fossils made by Mr. Clifton, which was forwarded to England to Mr. A. Sanford, F.G.S., and displayed in the Museum of the Somersetshire Archaeological and Natural History Society in Wellington and it is claimed to have been "the earliest evidence obtained of the presence of Mesozoic beds on the Australian continent.''

The year 1869 is specially noteworthy on account of the publication by the Geological Society of the paper by Mr. Charles Moore on ''Australian Mesozoic Geology and Palaeontology,'' in which, *inter alia*, is given an account of the fossils collected by Mr. Shenton from the Greenough flats and other districts in Western Australia. This collection, which contained several species new to science, is stated to have been ''not only the most numerous but the best-preserved Australian secondary fossils that had yet been publicly exhibited in Great Britain.''

Mr. W. H. Huddleston, M.A., F.G.S., prepared an account of the collection of fossils and rocks collected by Mr. Forrest in the country north of the Gascoyne River, which was published in the year 1883 by the Geological Society. The paper contained a list of palaeozoic fossils, together with a description of a number of species new to science, all of which proved to be Carboniferous or closely allied forms.

Amongst the earliest more or less systematic official investigations into the palaeontology of the State were those carried out during the period when Mr. H. P. Woodward, F.G.S., occupied the position of Government Geologist, 1888 *et seq.*, on the collections made by him and his predecessor, Mr. E. T. Hardman, from the Cambrian, Devonian and Carboniferous formations of widely separated districts in Western Australia. The results of these investigations were published at intervals during the year 1890 under the general title of ''Notes on the Palaeontology of Western Australia.'' The description of the Brachiopoda, Mollusca, etc., was the result of the work of Mr. Arthur H. Foord, F.G.S. (at one time assistant Palaeontologist on the Geological Survey of Canada). The plant remains were briefly described by Mr. R. Kitson, F.R.S.E., F.G.S.; the Stromatoporoids by Prof. H. Alleyne Nicholson, M.D., F.G.S.; and the Corals and Polyzoa by Dr. Geo. J. Hinde, F.G.S. These proved to be a valuable contribution to the faunal study of Western Australia.

The inauguration of systematic geological survey work on modern lines furnished Western Australia with a series of palaeontological publications of which there have been issued seven volumes containing fifteen separate articles under the general title of ''Palaeontological Contributions to the Geology of Western Australia.'' The series contains many important studies of the fossil fauna and flora of Western Australia by some of the leading palaeontological specialists.

Palaeontological researches have also been carried out under the auspices of the Western Australian Museum, whilst the results of several important studies by Messrs. L. Glauert, J. L. Reath, T. Withers, and F. W. Whitehouse, M.Sc., have appeared in the pages of the Journal and Proceedings of the Royal Society of Western Australia. The results of the local palaeontological researches have furnished much valuable information relating to the faunal relationships of the strata from which the fossils were derived and of their stratigraphical equivalents not only in the countries bordering the Indian Ocean, but also in China and Great Britain, in addition to being of fundamental significance with relation to palaeogeography, climatic vicissitudes, and problems of biological history. Palaeontological research is still being carried on with increasing energy.

During the course of this address, a field of gathered fact and growing generalisation has been traversed, and an endeavour made to show that Western Australia, which forms but a fractional part of the globe, has added its quota to the general facts and principles of earth history. And as one reflects not so much upon what has already been accomplished but as to what may be possible in the future, for the necessity for further knowledge is insistent, the prophetic words of Seneca of 2000 years ago cannot but commend themselves to our admiration, besides furnishing a keynote for the future.

Seneca in Book VII of his "Quaestionum Naturalium," a Latin production constituting one of the few works of its time bearing upon the facts and phenomena of Natural History Science, reminds us that:

"Many discoveries are reserved for the ages still to be, when our memory shall have perished. The world is a poor affair if it do not contain matter for investigation for the whole world in every age. *Some of the sacred rites are not revealed to worshippers all at once. Eleusis contains some of his mysteries to show to votaries on their second visit.* Nature does not reveal all her secrets at once. We imagine we are initiated in her mysteries; we are as yet but hanging around her outer courts. These secrets are not open to all indiscriminately. They are withdrawn and shut up in the inner shrine. Of one of them this age will catch a glimpse; of another the age that will come after."

Printed for the Royal Society of Western Australia by R. S. Sampson, 971-973 Hay Street, Perth.